Physical design of suspension device based on Halbach discal permanent magnet array

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Abstract: The model of gravity device is designed independently by disc Halbach permanent magnet array rotating disc. The parameters of the actual suspension device are provided. The relationship between gravity and suspension force is analyzed theoretically. The factors affecting the suspension effect are verified. The mechanical structure of the magnetic suspension rotating disc is designed and the basic principle of the suspension device is pointed out. The factors affecting the suspension performance are studied and analyzed in detail, and the test scheme is put forward. When the suspension function is realized, the duct fan is added to make it run freely in the horizontal direction.

1. Introduction

At present, Meisner effect and Lenz's law both provide mature application schemes for antigravity suspension system. Meisner effect is a quantum physics phenomenon, involving high temperature superconductivity, and the experimental operation cost is high. The application site has high limitations. Lenz's law is a classical mechanical phenomenon, which involves the mutual transformation between electric field and magnetic field.

In the 1980s, Professor Klaus Halbach proposed a concept of Halbach permanent magnet array, which combines radial and tangential arrays. The result of synthesis is that the magnetic field on one side increases while the other side decreases. It can be used in electromagnetic turnTables, electric levitation and permanent magnet brakes. This levitation device provides an ideal reality way.

Designing of Gravity Device Model Using Halbach discal permanent magnet array turnTable, [Analysis and calculation of multi-disk Coreless Permanent Magnet Synchronous Motor Based on Halbach array] proposed the electromagnetic force formula of disk array. [1]The essence of suspension is to embody gravity balance. The gravity balance device has a wide application value. It can be used in the fields of construction, rail transit and aerospace. This paper provides various parameters of the actual design of the suspension device. On the basis of vertical suspension of the device, the forward and backward free movement of the device can be controlled. Based on the experimental principle put forward by predecessors, the important indexes of suspension of gravity suspension device are analyzed.

2. Suspension device structure

In the experiment, a new device structure was designed. A mechanical support with 380 mm axle spacing of carbon fiber material was used. Four magnetic suspension turnTables with magnets were installed. The reaction surface was made of pure aluminium plate of type 1060.

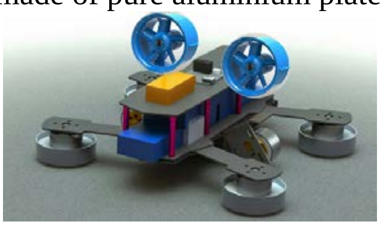

Fig.1 Simulated figure of suspension device

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3. Basic design rules and design parameters

3.1 The principle of Halbach discal permanent magnet array

The normal magnetic induction line of the magnet points from the N pole to the S pole, changing the placement order of the magnet blocks. The N pole and S pole are placed alternately, and the rotating disk will form a unilateral magnetic field, which generates the repulsive force. Halbach magnetic ring combines the radial and parallel arrangement of magnets [2]. If the end effect is neglected and the permeability of the surrounding magnetic conductive material is regarded as infinite, the permanent magnet structure will eventually form a unilateral magnetic field.

3.2 TurnTable structure

Based on the disc Halbach principle, the grooves of 12 magnets can be embedded by 3D printing technology, and the middle part is used to fix the motor. Ensure that the bottom of the turnTable does not protrude and there will be no mechanical friction with the aluminum plate.

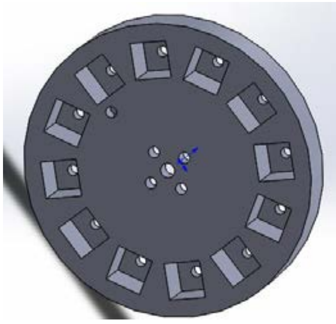

Fig.2 the picture of turnTable

3.3 Bracket height

As a buffer device, the bracket can protect the turnTable. Springs and hard plastics can be used to ensure the response speed of the turnTable starting. If the turnTable is placed on the aluminium plate to rotate directly, it will cause serious wear and tear; as for the accuracy of suspension, if the turnTable rotates too far away from the aluminium plate, it will not produce inductive magnetic field. The ideal starting distance between turnTable and aluminium plate is 2-3 mm measured by many experiments.

3.4 Calculation formula

The disk Halbach suspension force is deduced theoretically and the critical value of gravity balance is calculated. The disk number array can be equivalent to the radial integration of linear arrays with different polar distances, and the polar distance (τ) and the linear velocity (v) are functions of radius (ρ). By Lorentz gauge and boundary condition formula:

$$B_z = B_{z0} - \frac{\partial A_{2x}}{\partial y} \tag{1}$$

Halbach discal suspension force formula:

$$F_{yc} = -\frac{n}{2}\mathrm{Re}\left(\int_{r_1}^{r_2} \left(\int_{2\tau} \left(\int_0^L J_e B_z^* dy \right) dz \right) d\rho \right) \tag{2}$$

Je is the induced current, B_z is the static magnetic flux on Z vector, B_z^* is the conjugate complex of Bz. Surface integral is carried out for two times of the polar distance, and the result is taken as the real part. r_1 and r_2 are the inner and outer radius of the magnet disk, and N is the polar logarithm.

Gravity formula:

$$G=mg \tag{3}$$

The mass of the measuring device is 5.02 kg, and the experimental site is Chengdu, China. To calculate the gravity acceleration, the latitude of Chengdu must be determined first. The latitude of Chengdu is 30.67 degrees, and the calculated gravity acceleration of Chengdu is 9.782 m/s^2.

Gravity Acceleration Formula

$$g = g_0 \frac{1-0.00265\cos\theta}{1+\frac{2h}{r}} \tag{4}$$

When the body gravity is equal to the magnetic levitation force, the device is suspended. [4]

$$Fyc=G \tag{5}$$

4. Factors affecting suspension performance

4.1 Motor speed

When the magnet turnTable has a certain speed, there will be magnetic force. The experimental results show that the turnTable does not need a long acceleration start-up time at 1000r/min, the motor starts at 1000r/min, and realizes suspension at 1500r/min or so. When accelerated to about 2500 r/min, the suspension height does not increase with the acceleration of motor speed. The vertical coordinates are in millimetres, because of the support of the base bracket, the starting height is 2mm, and the abscissa coordinates are the rotational speed of the motor per minute.

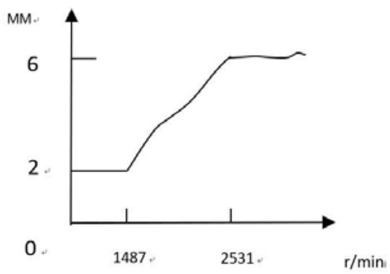

Fig.3 Relation between Speed and Suspension Height

4.2 Permeability magnetic material

In the experiment, copper plate and aluminium plate were chosen as the comparison. The suspension effect of copper plate was better when the suspension device was the same and the thickness of the plate was 5 mm. However, according to the market price, the use cost of copper plate is higher. The suspension performance of pure metal plate is good, and the suspension performance of alloy material is unstable. According to the magnetic properties of metals, they can be divided into diamagnetism, paramagnetism, ferromagnetism, antimagnetism and submagnetism. It is ideal to use diamagnetic material instead of paramagnetic metal material, which will make the magnet turnTable adsorb directly on the reaction plate. [3]

4.3 Reaction plate thickness

The thickness of 2MM, 3MM and 5MM aluminium plate is verified in the experiment. The experimental results show that the thicker the aluminium plate is, the higher the suspension height is. The thickness of the reaction plate also needs to consider the production cost.

Table1. Effect of Aluminum Plate Thickness on Suspension Effect

thickness/mm		Speed/r/min	Height/mm
2		3000	1.6
3		3000	2.3
5		3000	2.8

4.4 Surface area of turnTable magnet

There are 12 magnets on one turnTable, 12 square centimeters on one and 48 square centimeters on four. In order to test the effect of the surface area of the rotating disk magnet on the load of the device, the surface area of the single magnet is 18 square centimeters, and the total surface area of the magnet is 72 square centimeters. Through experiments, other variables are controlled unchanged to ensure the agreed suspension height and increase the surface area of the turnTable magnet can increase the load of the device.

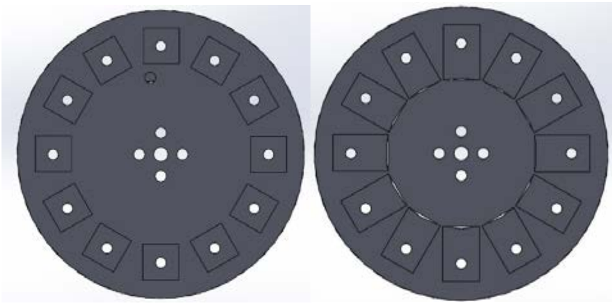

Fig.4 Contrast of turnTable area

5. Prototype production

5.1 Mechanical structure

In order to reduce the weight of the device itself, the material of glass fiber is not selected, and carbon fiber material is used as the body structure. The three-dimensional printing technology is used to make the base bracket of the two devices, which ensures that the turnTable has a certain distance from the aluminium plate when starting.

5.2 Motor control

By using F3 chip to control the motor, four motors can start and stop at the same time. The accelerator of the remote controller can increase the speed of the motor and achieve sTable suspension speed. F3 chip controls four electronic governors and four electronic governors are connected to one motor respectively. In the process of circuit layout, the circuit is not subject to electromagnetic interference . The brushless DC motor is used in the motor, and the motor with larger torque must be selected, because the rotating disc has large mass and strong inertia when rotated.The external structure of the brushless DC motor is modified, and the motor is stably connected with the magnet turnTable and fixed by four flat head screws. Note that the reaction surface of the turnTable must be horizontal and smooth to prevent scratching of the aluminum plate.

Fig. 5.ESC 1 to 4 control the motors of four magnet turnTables, and ESC 5 and 6 control the motors of two ducted fans. The remote controller has six channels to control the suspension device.

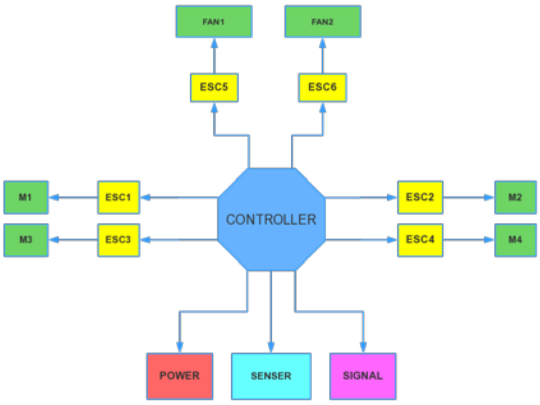

Fig.5 Motor Control

5.3 TurnTable design

3D Print four turnTables and insert a cubic magnet block with a side length of 1 square centimeter into the turnTable to ensure that the magnet block will not fall off during the high-speed rotation of the turnTable. The bottom of the turnTable should be smooth and the gravity distribution should be uniform.

5.4 Fan drive

Four turnTables can make the device levitate horizontally. If the device moves horizontally, it needs to install culvert fans and control two motor fans through F3 controller. Attention should be paid to the position and fixing mode of the fan. The fan can be placed on the top of the device to ensure the even distribution of gravity. The fan can also be placed in the center of the device to achieve an integrated structure.

5.5 Battery power consumption

Batteries determine the suspension time of the device. The greater the output power of the battery, the greater the suspension time and load. In this experiment, 22.2V 2600mAh 25C battery was used and suspended for 10-15 minutes at full capacity.

6. Conclusion

The factors affecting the suspension effect of the device have been clearly analyzed. The prototype has been made and the actual experiment has been carried out. The experimental method can be extended to other experimental parameters, such as replacing the magnetic conductive material and increasing the surface area of the magnet. On this basis, the suspension effect can be tested. The use of lithium batteries with larger capacity can improve the suspension time, put into practical application, and effectively solve the physical transportation problems.

With the rapid development of China's logistics industry and the increasing demand of consumers for logistics speed, there are unmanned warehouses in the logistics industry, mainly using unmanned sorting carts to sort goods. However, the manufacturing cost, maintenance cost of a large number of unmanned sorting cars in unmanned warehouses, and the transformation cost and procurement cost required for ordinary freight factories to use such cars are very high. The control technology itself is less difficult, and it is suiTable for the transportation of fixed track and the installation of suspension chassis. It is equivalent to customizable module. It only needs to redesign size to provide suspension chassis when transplanted to other similar fields. Its load can be determined by users. Because of its simple structure, magnetic levitation site is a customizable modular component, and its application field can also be extended to the transportation of goods through tunnel traffic in cities. If it is widely used in the field of logistics, it can be extended to the field of manned transportation and urban rail transit. Community stations can transport passengers directionally, providing a new mode of transportation for urban traffic.

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